



ROCKFALL MANAGEMENT PROGRAM

TDOT MATERIALS & TESTS DIVISION, GEOTECHNICAL ENGINEERING SECTION

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Photo by Harry Moore
Golder Associates

TDOT Rockfall Management Program

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Tennessee Department of Transportation
Geotechnical Engineering Section
6601 Centennial Boulevard
Nashville, TN 37243-0360
615-350-4132



Authors

Robert Jowers, P.E.
Lori Fiorentino, P.E.

Executive Summary

The purpose of this document is to standardize and centralize the Tennessee Department of Transportation Rockfall Management Program (RMP). TDOT considers the safety of hazardous rockfall sites paramount, and takes the risks associated with rockfall hazards, seriously. A ten year budget estimate is included for purposes of prioritizing future rockfall mitigation projects. This document describes the program to manage the rock slope hazard risk of Tennessee, and will be assessed and updated as required to meet the demands of TDOT rockfall risk management.

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INTRODUCTION

i.1 Rockfall Hazards and Safety

Roadway excavation cuts in rock are capable of releasing loose debris, and becoming a rockfall. Roadways constructed alongside existing rock cliffs present a danger of rockfall, as well. The rock debris released during a rockfall event can vary greatly in size and scope. Some examples of the circumstances that make rockfalls hazardous to the public are listed below:

1. Rock can strike a vehicle or person directly.
2. Rock can fall within the roadway cause an obstruction. In an attempt to avert the rock obstruction, an automobile collision could occur. This scenario poses risk potential when posted speeds are relatively high, and the roadway geometrics offers minimal driver site distance.
3. Traffic is detoured onto alternative roadways of often reduced capacity. This is of significance in rural mountainous areas where limited roadway access already exists.

All three of these scenarios have occurred and do occur in the United States and in the state of Tennessee.

Due to the nature of our rugged, mountainous terrain, Tennessee has many hazardous rockfall sites. As time passes, these rockfall sites can become more hazardous, and will continue to become less stable due to the continued weathering and freeze thaw cycles. The weathering cycles can cause the rock mass to loosen and move along the joints and discontinuities, potentially allowing rock fall debris to be released.

i.2 The History of TDOT's Rockfall Management Program

In 1987, FHWA began directing state DOT's to assess the hazard potential of rock slopes following a terrible accident and legal claim occurring in Colorado. Following that incident, FHWA provided guidance for state DOT's to rate the rock slope hazard potential using a standardized rating system. An NHI training class was developed in order to assist state DOTs in implementing such a rating system for their state.

The TDOT Rockfall Management Program began with a research project geared to rating the hazardous rockfall sites across Tennessee, and supply a searchable inventory database to the state. The research project began in 2001 and was completed in 2008. The research project eventually was supplemented to include a GIS component so the user could see individual rockfall sites on a viewer as a clickable icon. The information collected from the research project is used to list and track hazardous rock slope sites, and proactively identify potential sites that will become mitigation projects to budget in the future.

In 2007, TDOT programmed its first project described as a "Rockfall Remediation Project". Programmatically, the type of work was grouped within the "Safety" projects. Since then, TDOT has programmed contracts and mitigated the hazard of approximately twelve rock slopes. Although TDOT has had several rockfall emergency occurrences, and funded under an emergency contract, none of these programmed contracts were considered emergency in nature.

In 2013, TDOT procured a rockfall engineering consultant to re-rate the top 50 sites from the initial inventoried rockfall sites list. The list became known as the "Top 46", because four of the rockfall sites had been mitigated to a degree that they no longer were deemed hazardous or were already being assessed and under development.

CHAPTER 1: TDOT ROCKFALL INVENTORY

1.1 The Rating Score of Rockfall Hazards

In an effort to consistently rate the value of hazardous slopes in a standardized manner, FHWA adopted a Rockfall Hazard Rating System (RHRS). In the early 1990's NHI delivered standardized instructional workshops to various state DOTs. TDOT adopted a field sheet (shown as Figure 1) in conformance with the recommended FHWA RHRS Field Sheet.

Each potential rockfall site is rated individually using the TDOT RHRS Field Sheet. The field sheet gives eight different evaluation criteria. These criteria are an indication of the individual rockfall site characteristics. Even though some of the geologic characteristics could be considered subjective between different raters, much of the other characteristics are straight forward objective geometric observations such as ADT, ditch width and curve data. The RHRS is the industry standard recognized by FHWA.

Using the TDOT RHRS Field Sheet, a total score is given relative to the hazardous condition of the rock slope. These scores range from 0 to 800. Higher scores are indicative of higher rock slope hazard risks. Scores are broken down by potential of risk in Table 1.

Table 1 - Rating score versus risk potential

Score Range	Description
<200	Lower Risk Site
200 - 350	Moderate Risk Site
350 - 500	High Risk Site
>500	Very High Risk Site

II. Site and Roadway Geometry

1. Slope Height (ft) estimated _____		2. Average Vehicle Risk (AVR) $AVR = \frac{ADT \text{ (cars/day)} \times (\text{Rock Slope Length}) \times (DSD)}{(24 \text{ hpd}) \times \text{Speed Limit (mph)}}$	
alpha (a) _____ width (x) _____ ft	beta (b) _____ instrument height (H _i) _____ ft	Slope Length _____ ft Speed Limit _____ ft AVR = _____ %	4. Road Width (ft) _____
3. % Decision Site Distance (% DSD) Choose one: 3 9 27 81 OR Calculate: $\frac{\text{observed DSD}}{\text{(AASHTO DSD)}} \times 100 = \text{_____ \%}$		5. Road Width (ft) _____	
6. Slope Height (ft) $\text{Slope Height} = \frac{\sin a \times \sin b \times X}{\sin(a - b)} + H_i$			

5. Ditch Effectiveness				Effective catchment width (ft) _____					Launching Features? (yes or no) _____				
Design		Catchment Width (feet)	Recommended width for vertical slope	Percent of Design Catchment Width from Table					61 catchment shape? (yes or no) _____				
Slope Height (ft)	Recommended width for vertical slope			>90%	70%-90%	50%-70%	<50%						
0 - 40	18	18		Score with 6:1 or greater catchment slope	3	9	27	81					
40 - 50	18	24		Score w/ Poor Catchment OR Launch Features	9	27	81	81					
50 - 60	24	30		Score w/ Poor Catchment AND Launch Features	27	81	81	81					

6. Rockfall History				Field Judgment		Score
Benchmark	Frequency	No impact marks in the road, no rocks in the road, few rocks in ditch		No impact marks in the road, no rocks in the road, many rocks in the ditch		
		1 or less per year	2 or more per year			
Few	Several					3
	Many					9
	Constant					27
						81

7. Presence of Water on Slope

none	seeping	flowing	gushing
3	9	27	81

(choose one)

NOTES:

5

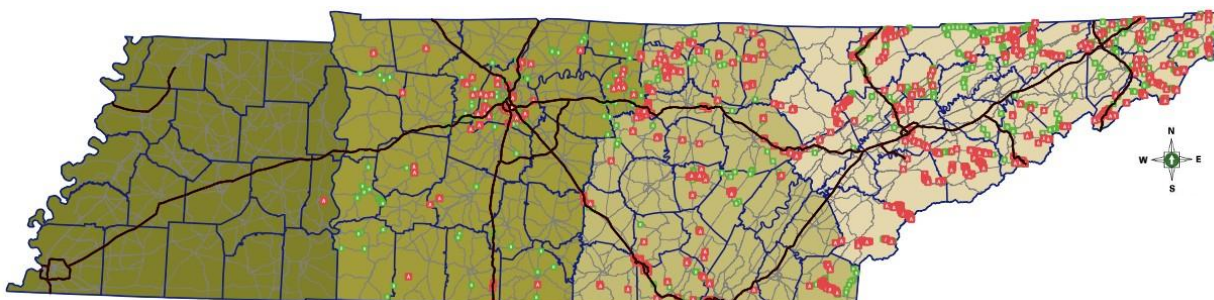


Figure 2 - Locations of "A" and "B" sites across Tennessee

1.2 TDOT's Hazardous Rock Slopes

With these data driven scores entered into a database inventory, the potential hazard of rock slopes around TDOT roadsides can be evaluated. This inventory can be used to prioritize the rock slope hazards, and prioritize rockfall mitigation funding as it becomes available.

During the initial rockfall rating program all rock slopes were rated either "A" (high potential of impacting roadway), "B" (low to moderate potential to impacting the roadway) or "C" (no potential to impact roadway). Locations of the "A" and "B" sites are shown in Figure 2.

There are approximately 1,956 high to moderate hazard rock slope sites statewide that could be expected to cause a safety problem due to rockfall by one of these scenarios. Of 1,956 rated rock slope sites, 972 rock slope sites are considered High Hazard, and 984 are considered Moderate Hazard. Most of the High Hazard sites ("A's") have an inadequate rockfall catchment ditch, and small driver site distances (small decision time). The breakdown of the rockfall sites among the Regions is shown in Table 2.

Table 2 - Number of hazardous rock slopes for each region.

Region	A (High Hazard)	B (Moderate Hazard)
1	582	629
2	288	166
3	100	188
4	2	1

1.3 Reassessment of Top 46 High Hazard Sites

Inventory reassessments of the 46 highest-rated rockfall sites were conducted during late winter 2013 to 2014. The reassessments were required to re-evaluate previously identified problematic rock slopes. Preliminary reports for each of the 46 sites were prepared through a procured contract with Fisher & Strickler Rock Engineering, LLC (FSRE) for TDOT. Each report identifies specific geological and geotechnical concerns and provides preliminary conceptual designs with stabilization cost estimates based upon the identified concerns, and the most current bid-tab data for reconfiguration and for stabilization of the rock cut slope.

Listed below in Table 3 are the separate rockfall mitigation item descriptions TDOT instructed FSRE to use in deriving budget cost estimates. These are items that will be used in the development of rockfall mitigation projects.

Table 3 - Stabilization Methods
• Manual Scaling
• Scaling and Trim Blasting
• Rock Anchor (Type I for Pinned Mesh)
• Rock Anchor (Type I for Rock Stabilization)
• Rock Bolt - 100 Kips
• Rock Bolt - 50 Kips
• Rock Bolt - 75 Kips
• Rock Dowel (Used as Shear Pins) #20 Bars
• Horizontal Drains and Casing
• Shotcrete Buttress
• Steel Reinforcement- Shotcrete Buttress
• Rock Anchor (Type I - Rock - To Secure Drape at Slope Crest)
• Rock Anchor (Type II - Soil & Rock - To Secure Drape at Slope Crest)
• Soil Nail Stabilization
• Rockfall Fence (Type I) - Low Impact - 100 to 500 kJ
• Rockfall Fence (Type II) - Moderate Impact - 500 to 1000 kJ
• Rockfall Fence (Type III) - High Impact - 1000 to 3000 kJ
• Rockfall Fence (Type IV) - Very High Impact - 3000 to 5000 kJ
• Rockfall Drape (Type I) - Double Twist Wire Mesh
• Rockfall Drape (Type II) - High Tensile 3mm Wire Mesh
• Rockfall Drape (Type III) - High Tensile 4mm Wire Mesh or Cable Net
• Rockfall Drape (Type IV (B)) - High Tensile Rope Net
• Hybrid Fence and Drape (Type I – IV)
• Modified Wire Net (Type I Hybrid Mesh)
• Modified Cable Net (Type III Hybrid Mesh)
• Machined Rip Rap (Class A1) - 2" to 1.25 ft.
• Gabions
• Concrete Median Barrier (Full)
• Road and Drainage Excavation (unclassified, acid producing – off site and on site disposal)
• Presplitting of Rock Excavation
• Scaling and Trimming (hand scaling, mechanical scaling and trim blasting)

CHAPTER 2: ROCKFALL MITIGATION PROJECTS

2.1 10-Year Budget Plan

Based on the data driven scores of the RHRS (geology, ADT, ditch width, etc.), and in collaboration with key personnel of TDOT Regional Operations Division, the Materials and Tests Division, Geotechnical Engineering Section provides the following list of rockfall mitigation projects to be programmed over the next ten years depending upon the funds availability. The budget estimate is meant to be used as a tool to anticipate future funding requirements of rockfall mitigation projects. Individual rockfall sites will most likely need to be added, replaced, or moved up in priority to accommodate an increase in a site's hazard rating score with time.

The budget estimate provided represent the cost estimate of the geotechnical stabilizing items of the rockfall site, and includes an additional 40% for roadway items such as mobilization, traffic control, asphalt pavement, pavement striping and marking, signage, and erosion control, etc. The percentage of roadway items was estimated using several previous rockfall mitigation projects.

Plan sets for sites having a budget estimate less than \$1 million will be developed and be placed in reserve should funding suddenly become available during the letting meeting schedule.

Since, this is a working document the provided budget estimate list may change based on site monitoring and site re-assessments.

Year 1

Site Location	Region	Budget Estimate
I-75, LM 10.5 (MP 114.5) - Knox County	1	\$4,993,800
SR-85, LM 3.8 - Fentress County	2	\$858,200
SR-25, LM 6.6 - Smith County	3	\$1,743,000
SR-37, LM 8.7 - Carter County	1	\$2,069,200
Total		\$9,665,000

Year 2

Site Location	Region	Budget Estimate
I-24, LM 2.1 (MP 136.2) - Marion County	2	\$3,007,200
I-24, LM 3.4 (MP 137.1) - Marion County	2	\$2,839,200
I-24, LM 4.2 (MP 137.8) - Marion County	2	\$2,254,000
SR-90, LM 2.2 - Campbell County	1	\$298,200
SR-148, LM 3.8 - Hamilton County	2	\$834,400
Total		\$9,233,000

Year 3

Site Location	Region	Budget Estimate
I-24, LM 5.6 (MP 132.7) - Grundy County	2	\$2,318,400
SR-37, LM 15.1 - Carter County	1	\$1,719,200
SR-159, LM 2.3 - Johnson County	1	\$476,000
SR-24, LM 9.9 - Smith County	3	\$5,110,000
SR-2, LM 5.1 - Hamilton County	2	\$1,001,200
Total		\$10,625,000

Year 4

Site Location	Region	Budget Estimate
SR-30, LM 7.4 - Bledsoe County	2	\$3,480,400
SR-8, LM 20.5 - Sequatchie County	2	\$5,699,400
SR-8, LM 20.7 - Sequatchie County	2	\$3,392,200
Total		\$12,572,000

Year 5

Site Location	Region	Budget Estimate
SR-40, LM 10.7 - Polk County	2	\$2,016,000
SR-40, LM 11.26 - Polk County	2	\$1,786,400
SR-40, LM 11.8 - Polk County	2	\$1,138,200
SR-40, LM 12.0 - Polk County	2	\$945,000
SR-40, LM 12.1 - Polk County	2	\$1,957,200
SR-40, LM 12.5 - Polk County	2	\$1,232,000
SR-40, LM 12.7 - Polk County	2	\$1,491,000
Total		\$10,566,000

Year 6

Site Location	Region	Budget Estimate
SR-115, LM 11.1 - Blount County	1	\$974,400
SR-115, LM 14.5 - Blount County	1	\$1,027,600
SR-115, LM 16.4 - Blount County	1	\$3,458,000
SR-68, LM 4.4 - Rhea County	2	\$2,472,400
SR-53, LM 22.5 - Jackson County	2	\$2,994,600
Total		\$10,927,000

Year 7

Site Location	Region	Budget Estimate
SR-141, LM 0.6 - DeKalb County	2	\$8,834,000
SR-135, LM 7.1 - Jackson County	2	\$1,534,400
Total		\$10,369,000

Year 8

Site Location	Region	Budget Estimate
SR-40, LM 13.1 - Polk County	2	\$7,372,400
SR-40, LM 13.5 - Polk County	2	\$1,866,200
SR-2, LM 4.6 - Hamilton County	2	\$691,600
Total		\$9,931,000

Year 9

Site Location	Region	Budget Estimate
SR-285, LM 4.4 - Van Buren County	2	\$2,886,800
SR-165, LM 19 - Monroe County	1	\$1,449,000
SR-165, LM 19.5 - Monroe County	1	\$768,600
SR-165, LM 21.9 - Monroe County	1	\$509,600
SR-165, LM 22.2 - Monroe County	1	\$365,400
SR-52, LM 1.2 - Fentress County	2	\$743,400
SR-53, LM 15.4 - Jackson County	2	\$1,661,800
SR-135, LM 15.5 - Jackson County	2	\$1,822,200
Total		\$10,207,000

Year 10

Site Location	Region	Budget Estimate
SR-40, LM 13.8 - Polk County	2	\$2,347,800
SR-40, LM 14 - Polk County	2	\$2,175,600
SR-40, LM 15 - Polk County	2	\$3,206,000
SR-40, LM 15.4 - Polk County	2	\$4,891,600
Total		\$12,621,000

CHAPTER 3: MONITORING OF ROCKFALL SITES

3.1 Reassessment of Hazardous Rock Slopes

The TDOT Geotechnical Section will keep the rockfall inventory current and progressing forward. It is proposed that re-rating of the rock slopes be determined based on the score as follows:

Score Range	Re-Evaluate
<200 and B	Every 10 yrs.
200 - 350	Every 5 yrs.
350 - 500	Every 3 yrs.
>500	Every 2 yrs.

With these established ranges, 326 sites across Tennessee would need to be re-rated every year. The rockfall mitigation projects listed in Chapter 2 (most hazardous rock slopes) will be reassessed on a yearly schedule and that the installation of monitoring instrumentation equipment be considered on a site-by-site basis. The numbers should decrease once the higher hazard sites are remediated.

3.2 Non-Inventoried Hazardous Rock Slopes

Notification of a non-inventoried hazardous rock slope is not uncommon. These notifications typically arrive from the TDOT Operations Division Maintenance forces, but concerned motorists can also provide valuable information. Non-inventoried rock slopes that are potentially hazardous should be initially visited by the Materials & Tests Division, Geotechnical Engineering Section to determine if a RHRS score should be conducted, and that rock slope will then be included in the databased inventory. It should not be surprising if the number of rock slopes inventoried and monitored increases.

3.3 Slope Instrumentation

Hazardous slopes not scheduled to be mitigated in 10-year Plan relatively soon, could warrant monitoring through slope instrumentation. There are many rockfall engineering consultants that offer installation and monitoring of these systems, should such systems ever be required. The complexity and cost of such systems depend upon the data required. Remote sensing of hazardous slopes could be required under certain circumstances.